Innovative Platforms for Upper Ocean Research

Robert A. Weller
Physical Oceanography Department, MS#29
Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1541
phone: (508) 289-2508 fax: (508) 457-2163 e-mail: rweller@whoi.edu
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S. Anderson and R. Trask
Physical Oceanography Department
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
e-mail: sanderson@whoi.edu ; e-mail: rtrask@whoi.edu

W. Paul and M. Grosenbaugh
Applied Ocean Physics and Engineering Department
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
e-mail: wpaul@whoi.edu ; e-mail: mgrosenbaugh@whoi.edu

LONG-TERM GOALS

We seek an improved understanding of the dynamics of the upper ocean and the physical processes that determine the vertical and horizontal structure of the mixed layer.

OBJECTIVES

Our ability to fully visualize, measure, and thus understand the physical processes active in the upper ocean in three dimensions on scales from meters to one kilometer is at present very limited. The objective of this project is the development of the technology to make measurements from three-dimensional arrays within the upper ocean. The long term technological objectives for this project are to develop the engineering tools to model, design, build, deploy, and retrieve a reliable horizontal submerged array.

APPROACH

Our approach is an integrated one, combining engineering design, static and dynamic modeling and operational experience. We are designing, modeling and deploying a moored, sub-surface, two-dimensional array which has instruments distributed both horizontally and vertically in the surface boundary layer. This effort would lead to the design and fabrication of a pair of sub-surface moorings that would be deployed in 100 meters of water with a horizontal element between the moorings capable of spanning 160 meters at a depth of 15 to 20 meters below the surface. Spaced along the horizontal member at 30-meter intervals would be five instrumented vertical strings extending to a depth of 45-50 meters. Two, 48-inch steel spheres would be used as buoyancy elements on the sub-

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surface mooring. Instruments measuring temperature, pressure, conductivity, current velocity, tilt, and acceleration would be placed along the horizontal member and on the vertical strings.

WORK COMPLETED

In 1997, a numerical model of a sub-surface horizontal mooring was developed to aid in the evaluation of horizontal mooring designs. The numerical simulation and study of the performance of the horizontal mooring was performed using a new general purpose software program, named WHOI Cable, for calculating static and dynamic modeling of moored and towed oceanographic systems. The simulation is built around a mathematical model of cable dynamics that includes the effects of geometric nonlinearities, components with non-linear elastic moduli, material bending stiffness, and material torsion. The software allows accurate three-dimensional modeling of systems in which mooring cables can go slack due to sea state forcing. The nonlinear, one-sided boundary condition at the seabed is modeled as an elastic foundation for systems with anchor chain lying on the bottom. The numerical implementation includes an adaptive time stepping algorithm to speed the solution of problems with high non-linearity. The software provided critical design information including mooring line tensions and system excursions at different current and sea state conditions and directions, and acceleration data due to sea state.

Two large sub-surface buoy moorings were designed to place the horizontal array under tension 20 meters below sea level by dragging one of the anchors to an appropriate location. Instrumentation for the first 100-meter long horizontal array consisted of five Richard Brancker, Ltd., temperature recorders and three Falmouth Scientific Instrument (FSI) 3D acoustic current meters. The FSI acoustic current meters measure three axes of current velocity, temperature, pressure and tilt and record the data internally. The velocity, temperature, pressure and tilt measurements provided the scientific data and helped to determine the vertical stability of the system. The system was deployed on August 19, 1997, off Provincetown, Massachusetts, in 100 meters of water. The FSI current meters and temperature/pressure sensors recording data every one and two minutes respectively. In addition to these instruments, a motion-measuring package was deployed in one of the two sub-surface mooring spheres. Three surface buoy guard moorings were positioned around the array site to protect it from damage due to fishing activities. One of the guard buoys was equipped with an internally recording wind speed and direction sensor to monitor the surface forcing. A significant storm passed through the area two days after deployment, testing the holding poser of the anchors and the integrity of the system under rough weather conditions. The array was successfully recovered on August 27, 1997. All instrumentation deployed along the horizontal element collected data for the entire deployment.

The data from the motion recorder deployed on the first horizontal mooring was analyzed to confirm the predictions of the numerical model. While a direct validation is not possible because the nearby NDBC buoy was out of service and a record of surface conditions is not available, the motion data, together with wind data does confirm that motion levels were small even during storm events.

Experience gained from the first deployment led to the design of a two-dimensional array which had sensors distributed both horizontally and vertically. The numerical model, WHOI Cable, was extended to allow for the modeling of branched and multi-leg structures. This modification was necessary to model the instrument strings that hung down from the horizontal member in the latest design of the horizontal mooring. The revised program was an integral part of the design process that was used to construct the new, more complicated mooring. To evaluate the unique capability of this two-dimensional array a joint engineering and scientific deployment was planned. The scientific focus was

to explore the coherence at short horizontal and temporal scales of the internal waves on the continental shelf, specifically targeting internal solitons. Working in conjunction with the US Geological Survey (USGS), a site was selected in Massachusetts Bay near Stellwagon basin in 85 meters of water.

The two-dimensional mooring was deployed on August 6, 1998. In addition to having a single, 160-meter long horizontal element tensioned at 20 meters depth between two sub-surface moorings, there was the addition of five 25-meter long vertical strings that were suspended from the horizontal member. The vertical strings had a horizontal separation of 30 meters and each had instruments at 20 meters, 25meters, 30 meters, 35 meters, 40 meters, and 45 meters depth. The vertical string in the center of the array was instrumented with an acoustic current meter, five temperature and conductivity measuring instruments and one acceleration sensing package. The other four vertical strings were each instrumented with six temperature recorders. The instruments at the bottom of the vertical strings also measured pressure. Two additional acoustic current meters were deployed along the horizontal member. Pressure sensors and motion monitoring packages were deployed at the ends of the horizontal member. The two-dimensional array was successfully recovered on September 1, 1998, after 27 days on station.

DorMor anchors were used to maintain the submerged horizontal array position, since they provided the highest drag resistance of all tested anchor candidates. Anchor alternatives that guarantee holding power, particularly in soft mud and clay bottoms under tensions with a large vertical component, were investigated. They include the Uryhof and Bruce vertical embedment anchors, as well as suction anchors. These anchors are now used to position oil exploration platforms, after geotechnical tests determine holding capacities of a site’s sea floor (Huang and Lee, 1998). Since maintaining the position of a submerged horizontal array is a high priority, these advanced anchoring methods could be considered if long-term deployments are required.

RESULTS

The technique developed to deploy the two-dimensional array was modified slightly to provide more real-time information about the depth of the horizontal member during the deployment operations. Pressure recording instruments mounted to the two, 48-inch steel spheres at each end of the horizontal member were inductively coupled to a surface floating line-of-sight radio transmitter. A receiver mounted on the ship monitored the pressure signal from the spheres as the ship tensioned the mooring. When the desired pressure reading was obtained, the ship ceased tensioning. The pressure reading was then monitored to ascertain whether the anchors were holding before casting off the towline. This technique worked well and provided a degree of confidence that the appropriate depth had been reached before detaching the mooring and leaving the site. Preliminary inspection of the data and supporting echo-sounding data from the ship indicates that the target depths were reached.

A total of 37 instruments were deployed along a 160-meter long vertical slice of the ocean between 20 and 45-meters depth. The two-dimensional array collected data for a total of 27 days. Data from a bottom mounted tide gauge deployed with the array will be used to remove the tidal pressure signal from the pressure measurements. Once the tidal signal is removed the pressure records can be analyzed to determine the vertical excursion of the instruments during the deployment. The motion data will be analyzed together with the pressure record and current data to better confirm the ability of the model to predict both dynamic and quasi-static response of the mooring and to evaluate the performance of the array and to determine its applicability as a new oceanographic tool.

Although past experiments have used radar to image the surface signature of solitons, this is the first attempt at visualizing the thermocline temperature perturbations with both high temporal and horizontal resolution. The temperature array deployed in August 1998 was successful at capturing the propagation of internal solitons through the thermocline. A movie generated from the temperature measurements collected every 15 seconds clearly shows the solitons moving from east to west. This is a unique data set that is expected to further our understanding of high frequency internal waves by allowing for a direct test of the non-linear wave dispersion relation used to describe these waves.

IMPACT/APPLICATIONS

The successful field deployment and recovery of an instrumented, two-dimensional array demonstrates the feasibility of using such moorings for scientific observations. In particular, it will be possible to investigate horizontal variability in the upper ocean on scales of meters to 100's of meters with high temporal resolution. Unlike towed thermistor chains, this new technology will allow for the complete measurement and resolution of the temporal and horizontal variability in the upper ocean.

TRANSITIONS

John Bonardelli, consulting for the project, is reporting on the recent deployment of similar submerged, long-line moorings for aquaculture in waters off Canada's Quebec province. Sixty-three concrete anchor blocks were deployed in protected waters, 88 in an exposed site, weighing up to 6,000 pounds each. The entire operation took only 2.5 days, utilizing a Canadian Coast Guard buoy tender.

RELATED PROJECTS

A horizontal mooring was deployed in August 1998 as part of an experiment conducted jointly by scientists and engineers at the Woods Hole Oceanographic Institution and the USGS (Bradford Butman). The experiment was designed to study the formation and propagation of internal waves and the role these waves play in mixing of the water column and re-suspension of bottom sediments.

Funding for a two-year mussel long-line demonstration project was received this year from MIT and WHOI Sea Grant, and the Massachusetts Aquaculture Grant. For this project a 160-meter submerged long-line mooring was deployed in October 1998 at the WHOI Buoy Farm.

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